Fermilab
Accelerator Division
Mechanical Support Department

3.9 GHz Cryomodule Transport Study Instrumentation Calibration

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Introduction

The response of the 3.9 GHz cryomodule to shock and vibration has been studied extensively in preparation for its transport to DESY. As part of those studies the response of three different sensors to a shock and vibration has been compared.

The three sensors are:

- A GP1 programmable MEMS accelerometer Manufactured by SENSR;
- HS1 Geophones manufactured by Geospace LP; and
- A Shocklog RD298 manufactured by ShockWatch.

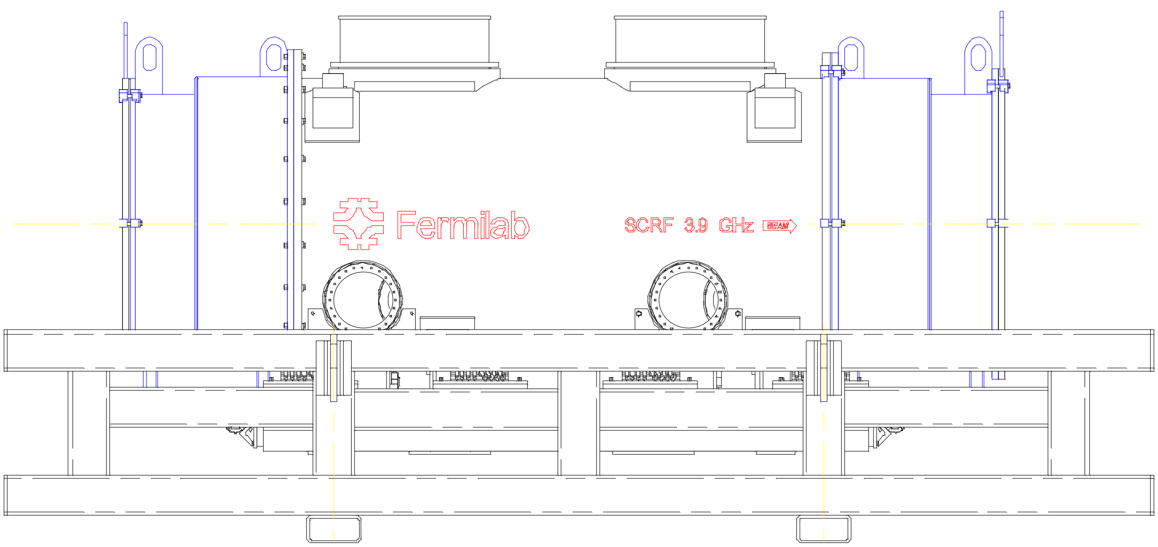


Figure 1: Final transport configuration.

Because of the duration of the actual transport from Fermilab to DESY, shock recorders provide the most efficient and reliable way to instrument the assembly during transport. During the studies, however, the assembly is has also been instrumented with geophones in order to determine peak shock, relative motion of the components and the frequency response.

Instrumentation and Setup

The calibration setup was based on the transport study instrumentation configuration. This consists of (2) Shocklogs (in red), (24) Geospace HS-1 Geophones (8 vertical, 8 transverse and 8 longitudinal in blue) and a GP1 device (in green) as shown if Figure 2.

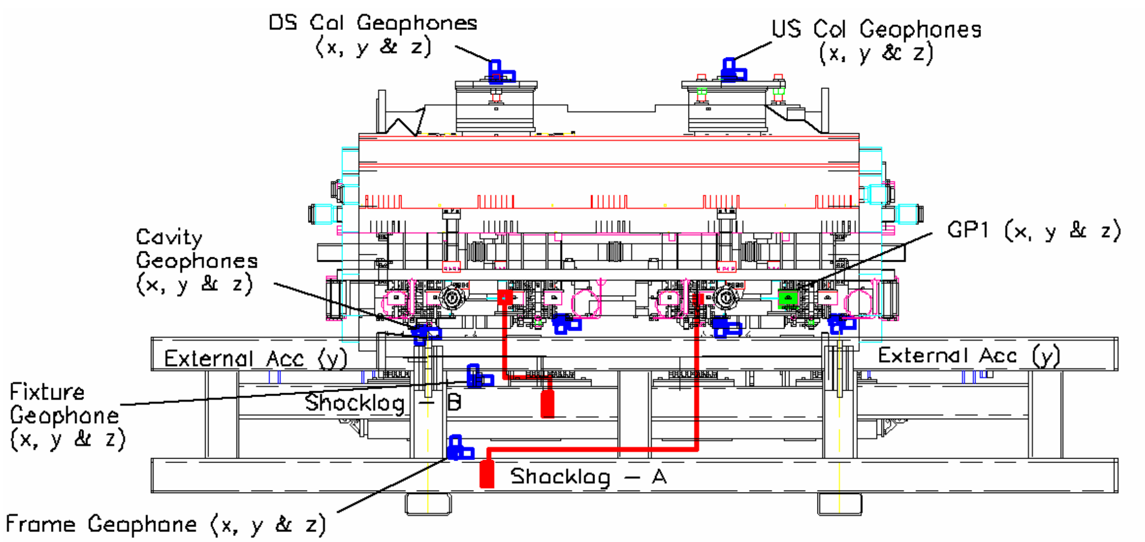


Figure 2: Instrumentation transport configuration.

All of the devices listed above were attached to a common base. The base was mounted on the bed of a light truck and the truck was driven at speeds of up to 60 MPH over a variety of roads. Although other calibration methods had been tried, over-the-road testing most closely emulates the shock and vibration distributions that will be experienced by the cryomodule during transport.

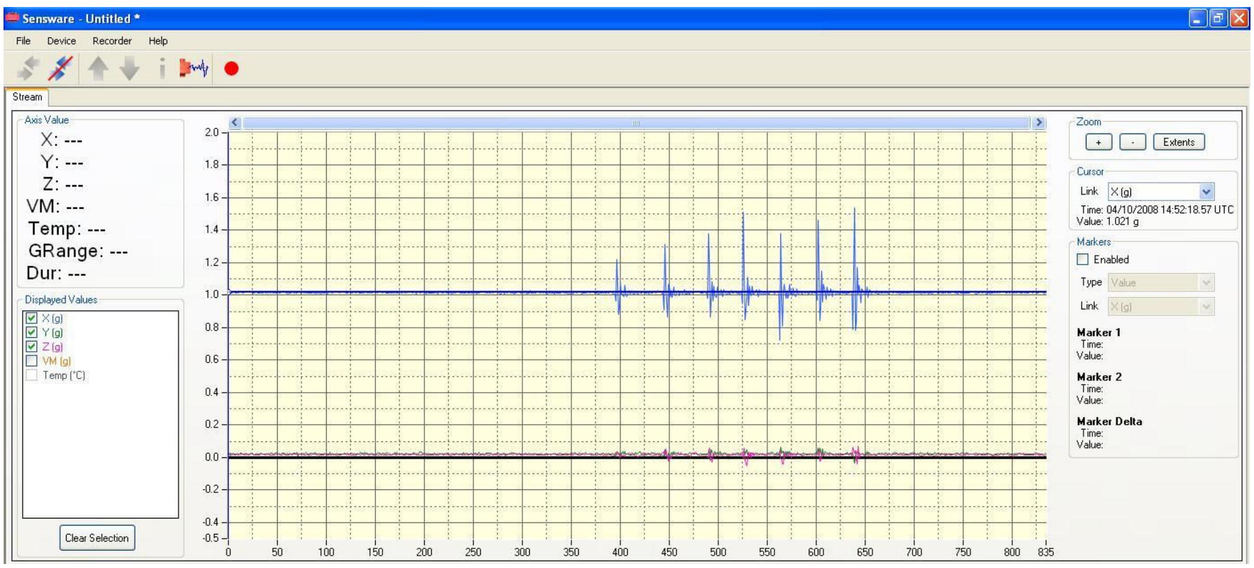
GP1 Programmable Accelerometer

The GP1 features[1]:

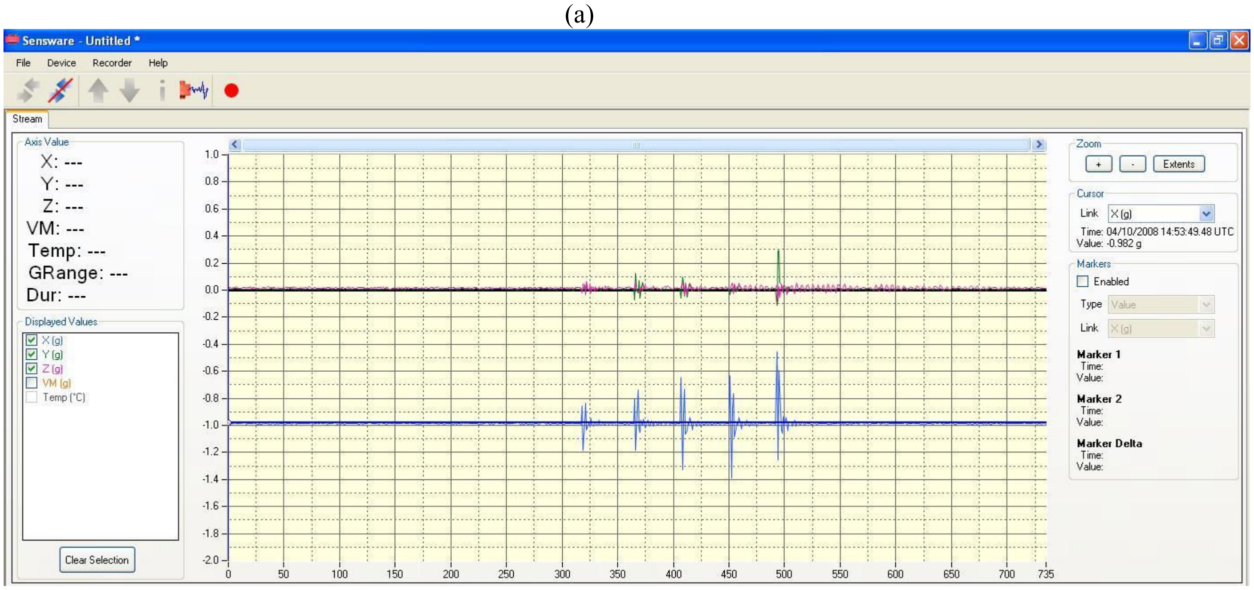
- Accelerometer type: 3-axis MEMS
- Accelerometer resolution: 0.001 g
- Accelerometer range: up to 10 g
- Frequency response: DC – 45 Hz
- Memory Capacity: > 570,000 Data points (Non-volatile EEPROM)

The GP1 device is a small, self-contained recorder that operates from two AA batteries. It incorporates a MEMS accelerometer, which is sensitive to both static and dynamic forces. The sensitivity to static forces allows the GP1 to auto-calibrate as demonstrated in Figures 3a and b. In Figure 3(a), the GP1 is upright and the vertical (x) axis reads positive 1 g. When the device is inverted as in Figure 3(b), the same axis gives a vertical reading of -1 g. The GP1 device provides a self-calibrated reference standard against which to compare the other two devices.

The GP1 can be programmed to record either continuously or to record only those events that exceed a specified acceleration threshold. During these tests, the GP1 was programmed to record continuously at a rate of 100 samples a second per axis.



(a)



(b)

Figure 3(a): GP1 response when upright. 3(b) GP1 response when inverted.

Shocklog RD-298

The Shocklog is an event recorder that samples the 3 components of acceleration once every 10 seconds and records any shocks above a threshold of 1 g (warning) and 1.5 g (alarm).

The Shocklog RD-298 features[2]:

- Dynamic range: 2.5 mg to 100 g
- Acceleration range: ± 1 to ± 100 g

Geospace HS-1 Geophone (4.5 Hz ± .75 Hz, 1250 Ω)

HS1 geophones are sensitive vibration detectors that generate a voltage proportional to velocity.

The Geospace HS-1 Geophone features[3]:

- Sensitivity (G): 0.453 V/cm/in ± 10%
- Open Circuit Damping (B_0): 0.28 ± 20%
- Damping Constant (C_D): 1295
- Coil Mass (m): 28 gm ± 5%
- Maximum Tilt Angle: 15 degrees ± 2 degrees (vertical and horizontal models)
- Coil/Case Displacement (peak-to-peak): --- (minimum); 0.05 in (maximum)

The output response curve is shown in Figure 4

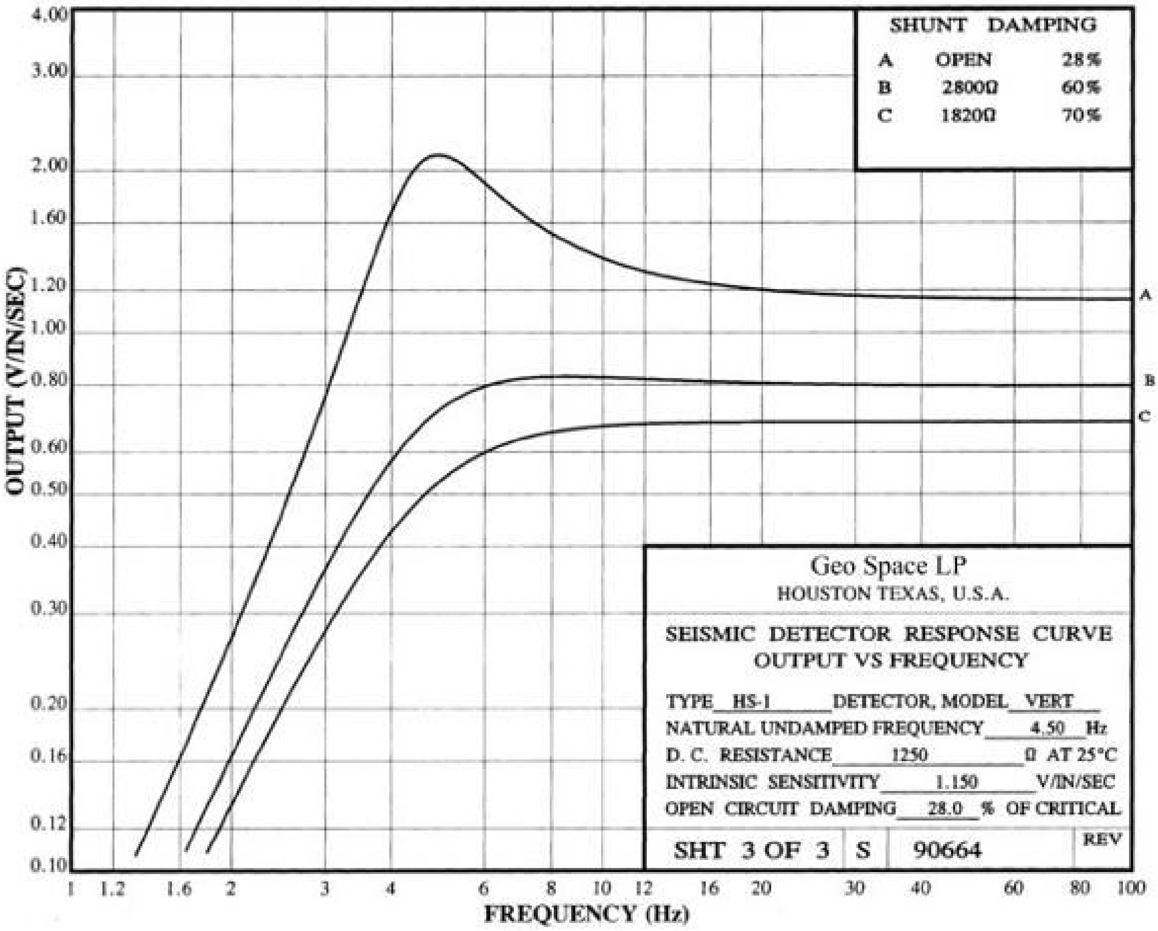


Figure 4: Geospace HS-1 (1250 ohm) response curve[3].

The 24 geophones were connected to six National Instruments (NI) NI-9233 4-channel, 24-bit ADC modules sampled at 5KS/s, and the data was recorded to a laptop hard-drive. A Diehard Portable Power Model 1150 (12 VDC) battery source was used to power this system.

Analysis and Results

As an initial consistency check, the correlation between the voltages of each of the 24 geophones was examined. The correlation matrix is as shown in Figure 5. Positively correlated channels show as light blue or red squares in the off diagonal elements. Uncorrelated channels show as dark blue squares in the off diagonal elements. Each channels falls into one of three groups depending on its orientation, vertical (Channels 1 through 8), transverse (Channels 9 through 16), or horizontal (Channels 17 through 24). The correlation pattern is consistent with that expected based on the geophone channel assignment and polarity.

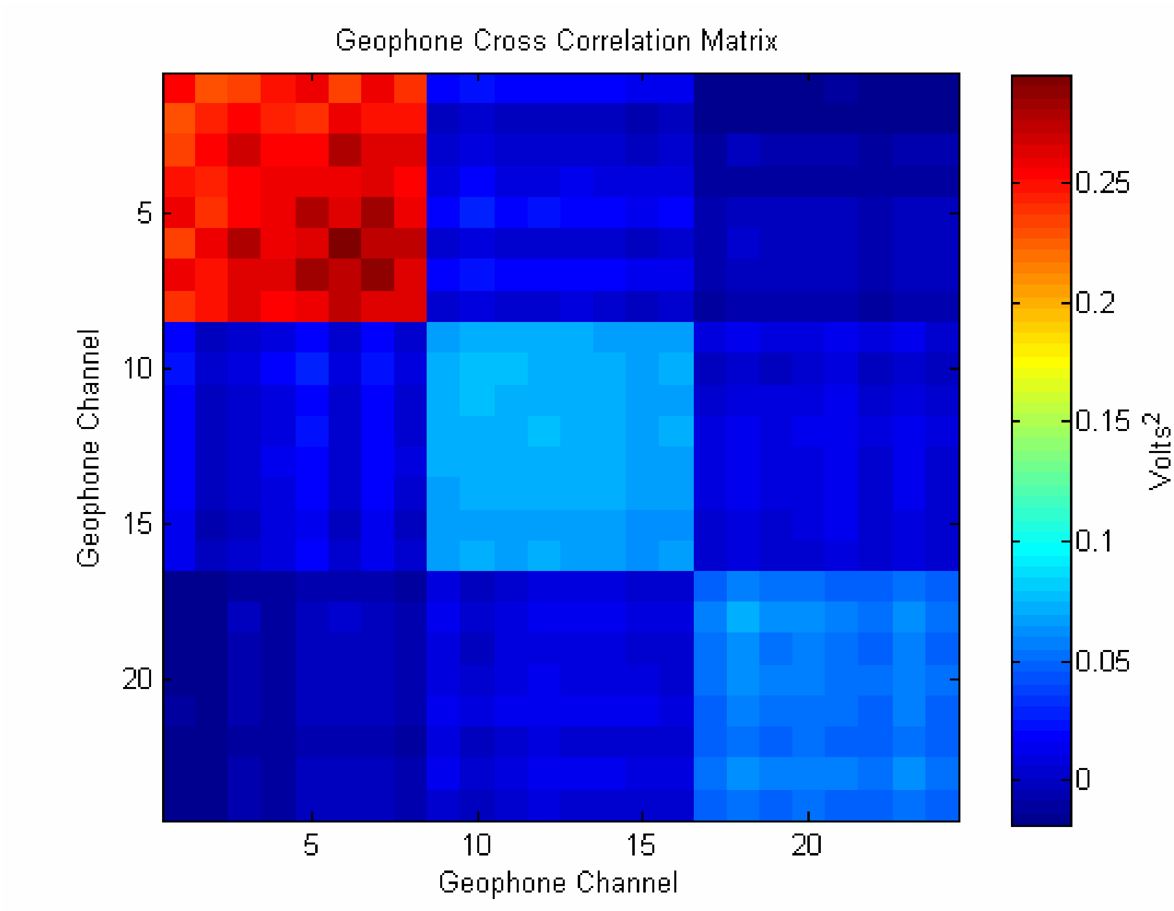


Figure 5: Geophone cross correlation matrix.

Figure 6 shows the relative geophone uniformity within in each group. The standard deviation within each group, 3.34% vertically, 7.15% longitudinally and 3.11 % transversely is well within the range expected from the manufacturer's variation specification of 10%.

To allow the geophone data to be easily compared to the GP1 data, acceleration was calculated by taking the first finite difference. The geophone data was then aligned in time with the GP1 data and the maximum magnitude of the acceleration over each one second interval was determined. The relative gain between the two devices was determined by fitting a zero-intercept straight line to the geophone acceleration as a function of the GP1 acceleration. This is shown in Figure 7. The two devices agree to 5%. This is well within the manufacturer's specification for the geophone gain variation (10%).

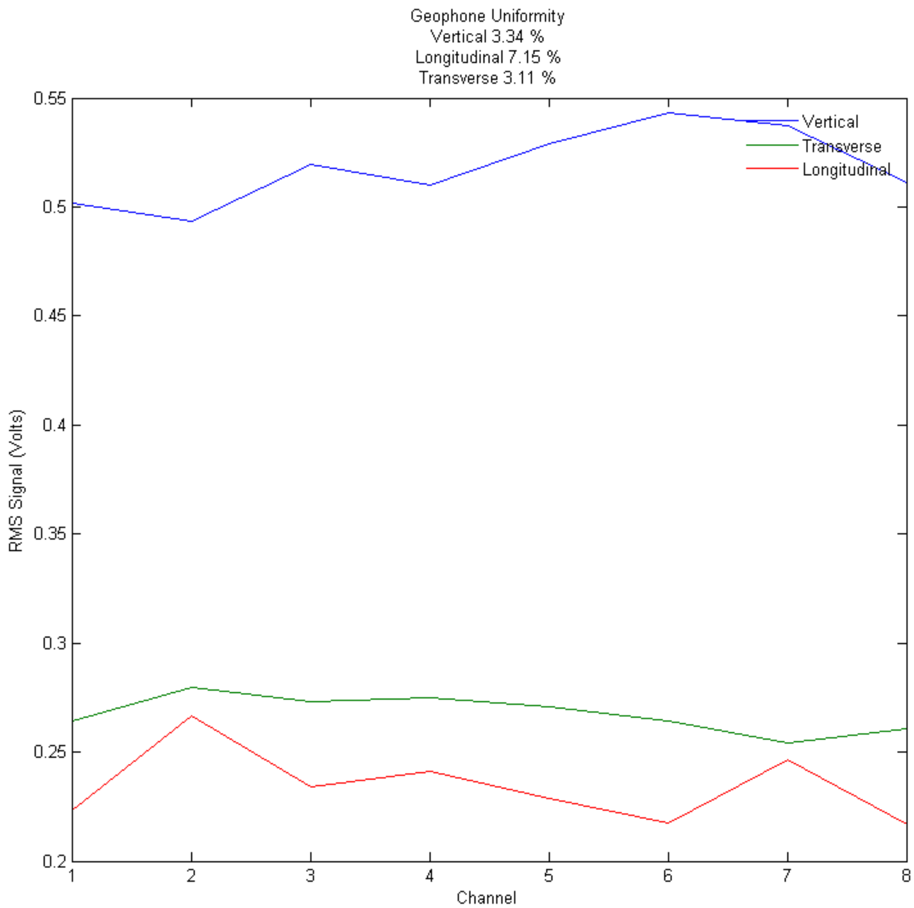


Figure 6: Geophone uniformity.

Figure 8 shows a similar acceleration comparison between the Shocklog and GP1 device. Although the two acceleration curves are well correlated, the overall level of acceleration measured by the Shocklog is only 71% of that measured by the GP1. This is much larger than the expected statistical error of the fit (2%). While the shock log has been the primary instrumentation in past transportations studies, the GP1 is a more accurate recorder and would be a better choice for the transportation of the cryomodule to DESY and for any future transportation studies.

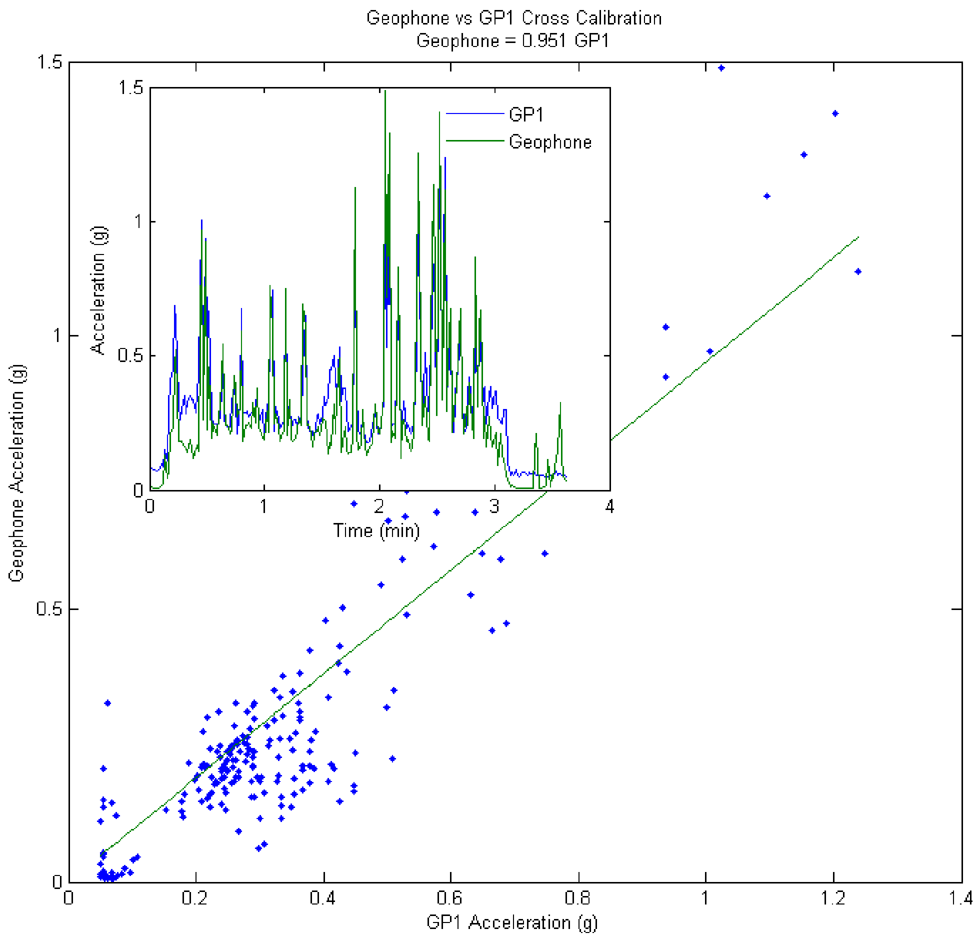


Figure 7: Cross calibration between (averaged geophone) and GP1 modulus.

Summary

The response of the three shock and vibration sensors used for the 3.9 GHz cryomodule transportation studies has been compared. The GP1 programmable accelerometer self-calibrates to the gravitational field of the earth so it was used as a reference for comparisons with the other two devices. The acceleration response of the geophones was found to agree with the GP1 calibration to 5%. This is well within with the geophone manufacturer's gain specifications. The agreement between the Shocklog and the GP1 was considerably poorer ~30%. Given the ease of use of the GP1 and its self-calibration ability, it should become primary instrumentation for the transport of the 3.9 GHz cryomodule to DESY and any future transportation tests.

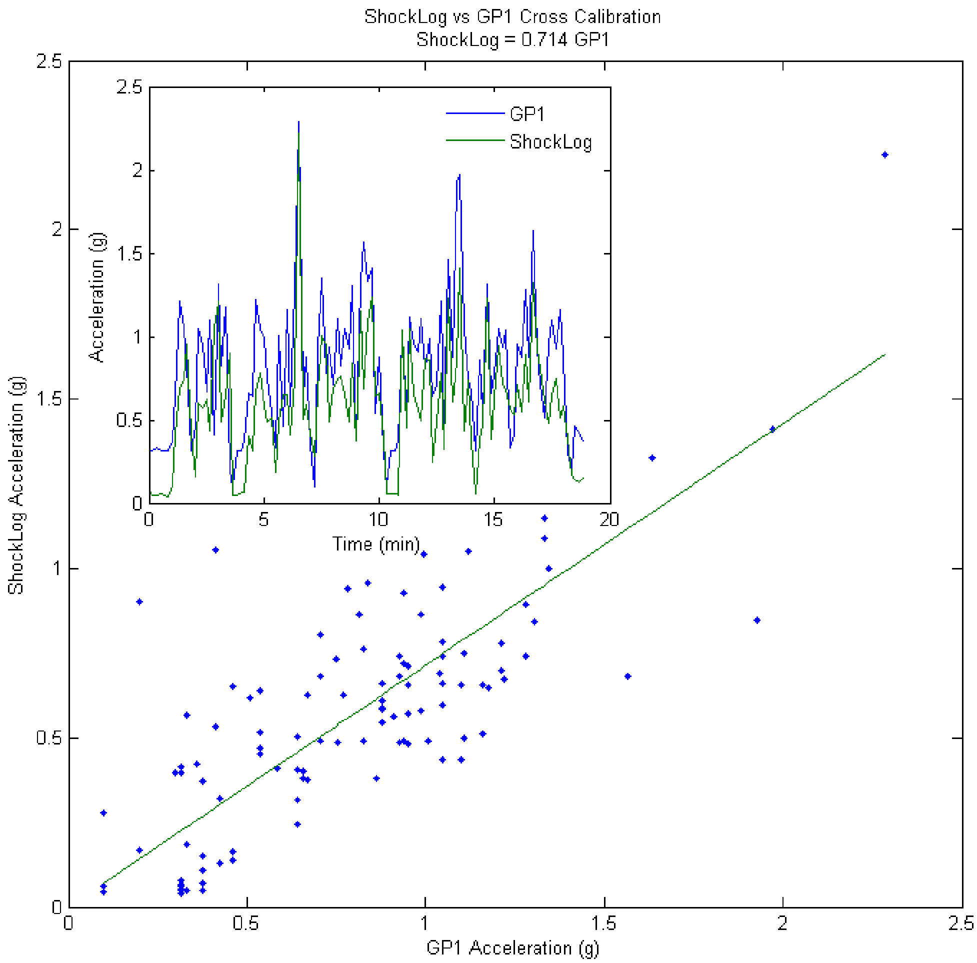


Figure 8: Cross calibration between Shocklog and GP1 acceleration modulus.

References

[1] http://www.sensr.com/gp1.html

[2] http://www.lamerholm.com/shipping/shocklog/shocklog-rd298.html

[3] http://www.geospacelp.com/hs1.shtml